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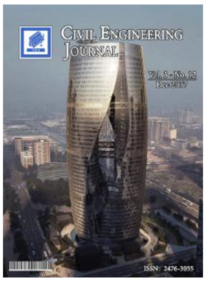

Protecting River Environment through Proper Management of Material Mining by Matrix Method (Case Study of A'la River in Iran)

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Abstract

Regarding the importance of rivers, appropriate management of aggregate mining is of great significance. Mining of river materials has a direct impact on environmental conditions of the river. Today, aggregate mining management represents a crucial topic in river engineering. Often selected based on the pattern of the considered river, matrix method provides a suitable approach to improve the river aggregate mining management. The present research aims at presenting the application of the matrix method in river material mining location evaluation. Given the capabilities of the matrix method for determining potential of mine area and aggregate mining method, this method can be seen as a suitable solution for reducing negative environmental impacts of river material mining. A'la River is one of the most important rivers streaming in Khouzestan Province (Iran), with its sediment load and mining potential being of critical importance. In this research, the reach of A'la River at the intersection of Rood-Zard River and Rahmhormoz diversion dam was studied for aggregate mining and application of matrix method. The main purpose of this work is to study the application of matrix method to A'la River. The results indicate braided pattern of the river and appropriateness of the matrix method. Available volume of aggregate for mining within the mentioned reach of A'la River was estimated as 50,000 m^3, and scraping method at a maximum depth of 1 m was proposed for mining of the aggregates.

Keywords: Aggregate Mining; A'la River; Braided River; Matrix Method; Scraping.

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1. Introduction

Rivers are among the most important natural resources, so that it is critically important to have them protection and preserved. During recent years, changes in river systems have resulted in environmental and morphological damages which have drawn the attention of water and environmental managers. River status studies in terms of erosion and sedimentation conditions comprise a major topic in any river-related engineering project [1]. In other words, morphological and geometrical changes in rivers are influenced by erosion, sediment transport, and deposition [2]. Population growth and subsequent physical extension of cities has increased the demand for river aggregates for construction materials in urban structures, road construction, and civil and industrial projects. Also, river aggregate is far more convenient to access than mountain aggregate.

Feasibility studies on aggregate mining potential and operation on rivers are among the most important studies in river engineering, widely affecting hydraulic, environmental, and morphological conditions of streams. In other words, river aggregate mining affects hydraulic regime of the flow which in turn results in variations in sediment load and

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erosion of the river bank, ending up with morphological changes [3]. Excessive aggregate mining represents a major environmental concerns because of its adverse effects on river ecosystem [4]. Excessive river mining results in subsidence of the riverbed which may lead to physical and environmental damages to the environment [5]. Also, it causes failure of the river banks, widening of meanders, widening of riverbed, scouring of bridges and levees, and threatening to farms and gardens in the vicinity of the streams [6]. Among positive effects of aggregate mining, one may refer to river training, increased discharge capacity, steep meander prevention, and river guidance toward dominant directions [7].

In a paper, morphological changes caused by sand and gravel mining in downstream of Mekong River in southwestern Asia were evaluated. The river flows through China, Thailand, Cambodia, Laos, Myanmar, and Vietnam. Based on investigations, it was found that, a total of about 34 million cubic meters of sediment has been accommodated along the river in 2011, with various fractions of the sediment hosted by different countries. Numerous morphological changes and hence environmental impacts have been resulted from inappropriate management of material mining along this river, further influencing the hydraulic structures constructed on the river, such as bridges and piers [8]. A study was performed on sand mining operation and related environmental impacts along Nzhelele River in South Africa. Findings of this research indicate that, inappropriate sand mining along the river has given rise to environmental problems and the risk of destructive floods [9]. In a review study, environmental impacts of river material mining in India were assessed. Studies showed that, improper mining of river reserves has caused numerous problems including elimination of vegetation coverage, destruction of ecosystems, increased degradation and erosion of rivers, environmental pollution and deterioration of beautiful river landscapes [10].

A major concern in aggregate mining is the proper management of the mining operation which represents a major challenge faced by river basins. Proper and timely management of the mining operation and appropriate mine location selection contribute to river training largely. For example, there are cases wherein aggregate mining is necessary to navigate the river toward a main stream. On the other hand, proper management of aggregate mining from rivers contributes to favourable environmental conditions along rivers. The flow pattern and flowrate affect the aggregate mining of rivers strictly. Also, the mining method (scarping, dredging, or pitting) shall be determined based on hydraulic and morphologic conditions of the river. The choice of mining site is also an important issue. Different zones along a river can be selected for aggregate mining, including terrace, active floodplain, inactive floodplain, and the riverbed. Implementation of international experiences, instructions, and standard codes in aggregate mining of rivers can improve the mining management via novel approaches. For example, when material mining of a river is concerned, one should take into consideration the following sites:

- Biological realm of aquatic animals in rivers with tidal zones,
- Major rivers and surrounding lands, and
- Aggregate-covered areas [11].

Also, it is noteworthy that, as far as material mining is concerned, large rivers are preferred over small ones, because of the following reasons:

- Availability of larger volumes of sediment load and river aggregates,
- Wider floodplains,
- Lower river disturbance, and
- Less aggregate mining impacts due to river characteristics [11].

Based on the pattern of the river considered in this study, matrix method is proposed to evaluate aggregate mining potential and determine the most appropriate method for the mining operation. Determining appropriate location for mining, efficient mining method, and appropriate season and time for the mining operation are the main challenges which should be addressed to attenuate the negative impacts of mining on the river. In the matrix method, the river matrix is used as a criterion to evaluate minable aggregate reserves along a river. In fact, it serves as a model to specify feasibility of aggregate mining and appropriate mining method for a specific river. Matrix method can contribute to decreased negative environmental impacts of aggregate mining of rivers. The main aim of the present work is the application of matrix method onto a reach of A'la River in Khouzestan Province (Iran) to evaluate the study area in terms of aggregate mining potential and specifications of the mine, so as to attenuate negative impacts of material mining on the river. In this research, the considered reach of A'la River including the intersection of Rood-Zard River and Ramhormoz Diversion Dam is studied and the matrix method is explained. Then, properties and conditions of the A'la River are studied and the matrix method is applied. Finally, the results obtained from the matrix method are discussed and analyzed.

2. Materials and Methods

2.1. River Characteristics

Rivers may possess various patterns and stream alignments. When studying rivers for aggregate mining, a particular default matrix may be considered for each of the three types of river, including (i) braided rivers, (ii) split, sinusoidal, or meandering rivers, and (iii) straight rivers, as explained in the following:

Braided river: Refers to as a river with a very wide bed in which the water passes through several linked together streams separated by bars and islands.

Split river: Such a river encompasses several permanent islands, so that the primary flow is usually divided into two (or more, in rare cases) streams.

Meandering river: It includes several alternative meanders which are connected by direct reaches. Such rivers go through low-slope paths and instable channels.

Sinusoidal river: It passes through a sinusoidal, low-slope, instable path.

Straight river: Rivers are generally not following a strictly straight direction. A straight river is rather the one with lower curvatures and sinuosity values smaller than 1.5 [7].

According to the river types, three matrixes have been defined for the matrix method, with each matrix containing four primary properties of the corresponding river, as follows:

- River size
- Mining site location
- Associated channel
- Type of deposit [12].

River size: River size is often considered as the main property of a river. It includes the basin area, geometric dimensions, and flowrate of the river. Based on the mentioned factors, in terms of size, rivers have been classified as small, medium, and large rivers. A small river is the one with a basin area of smaller than 100 km^2 and average top width of narrower than 15 m. The corresponding Figures for a medium river are 100-1000 km^2 and 15-100 m, respectively, and those of a large river are larger than 1000 km^2 and wider than 100 m, respectively.

Mining site location: Mining site can be located on either active floodplain, inactive floodplain, or riverbed. Environmental conditions of the river are of particular importance in site selection for material mining.

Associated channel: A river may include active channel(s), high-water channel(s), and/or abandoned channel(s). Figure 1 shows a schematic view of mining site location and different channels of a river.

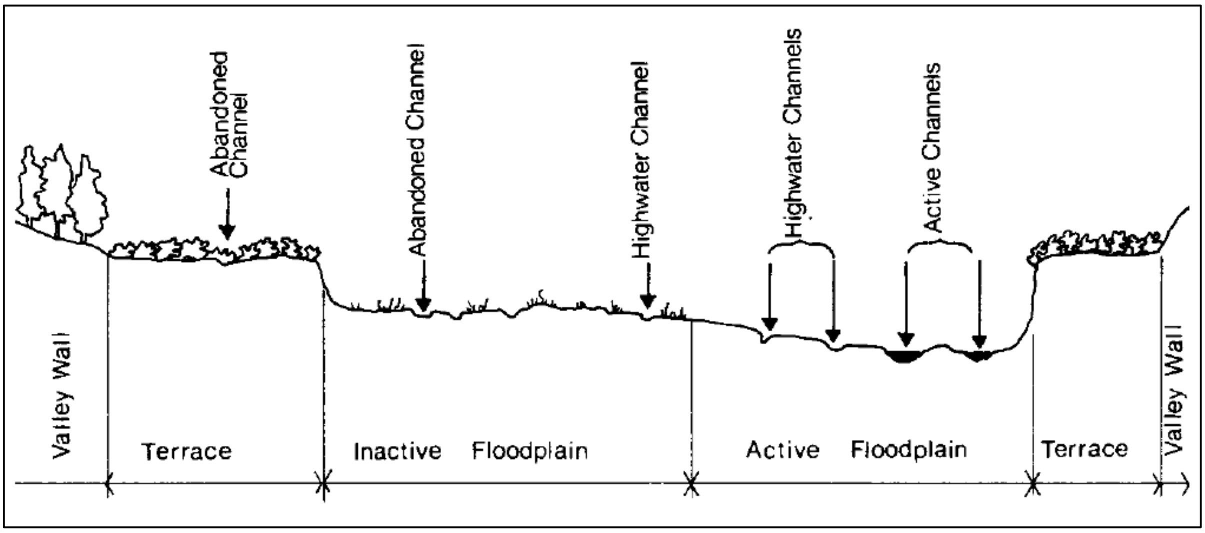

Figure 1. A schematic view of mining site location and different channels of a river [12]

Type of deposit: The deposits along the river may include riverbed sediments, point or lateral bars, mid-channel bars, inner and outer meanders, vegetated islands, and vegetated banks. Sedimentary bars, from which aggregates are mined, should not incur any environmental problem for the river system [7]. Figures 2 and 3 show material mining out of riverbed and inner meander of a river, respectively.

Figures 2. Aggregate mining out of riverbed by machineries

Figures 3. A view of inner meander of a river

Based on defined matrix for each river type with a specific pattern, there is also a blank matrix to be filled. For this purpose, one should begin with determining the river type depending on the river pattern and path. Then, the corresponding matrix is selected followed by filling in the blank matrix for the considered river. Finally, the corresponding matrix to the river type is compared to completed blank matrix to address the followings based on the rows and details of the matrix:

- Pattern and path of the river
- River size, mining site location, stream and bar types
- Mining potential
- Appropriate mining method for the selected location, so as to avoid severe environmental problems for the river
- Completing checklists about the basin and mining site location.

Assessment of the above-mentioned items can contribute to proper management of aggregate mining and environmental protection of the river as well as the mining area.

2.2. Study Area

A'la River is one of the main branches of Jarahi River in Khouzestan Province, southwestern Iran. This river is 106 km-long and covers a basin area of 2330 km^2. Severe floods flow in A'la River which cause serious damages to farms and hydraulic structure.

A reach of A'la River between its intersection with Rood-Zard River and Chamlishan Village near Ramhormoz Diversion Dam is located within a region with mining potential (Figure 4).

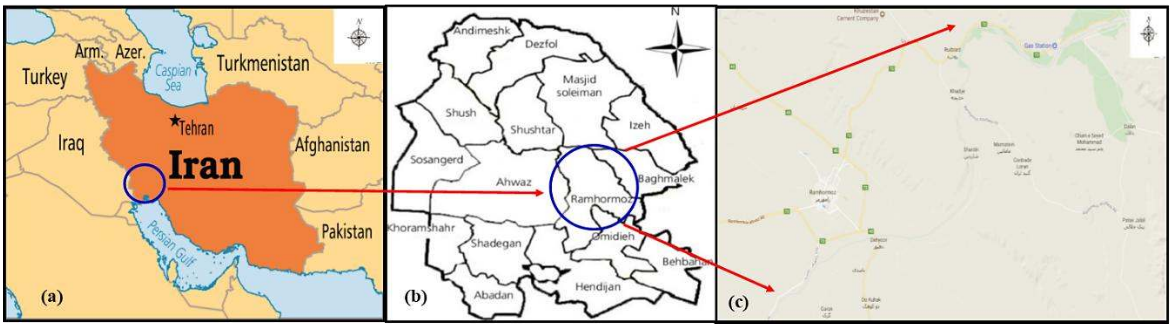

Figure 4. (a) Geographic position of Iran in the Middle East; (b) A'la River path within Khouzestan Province; and (c) Geographical position of A'la River and considered reach of the river for aggregate mining

The region with mining potential is near Shardin Village in the middle of Ramhormoz Township in Khouzestan Province, Iran. In this reach, as the river moves toward downstream, two branches are added to the river, namely Rood-Zard River and Talkh-Rood rivers, with the considered mining site being located at downstream of the two intersections. Irregular and unwise aggregate mining of A'la River can generate a lot of environmental problems. Figures 5 (upstream) and 6 (downstream) show the mining site location and A'la River path on satellite images.

Figure 5. Upstream of mining site location along A'la River

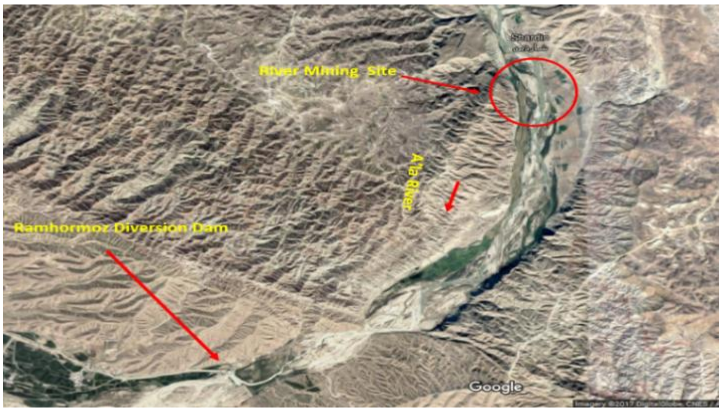

Figure 6. Downstream of mining site location along A'la River

2.3. Hydraulic Structures in the Study Area

There are two major hydraulic structures constructed on A'la River near the location considered for material mining. Zulfaqar Bridge is located at upstream of the mining location and Ramhormoz Diversion Dam is located at downstream of the location.

Zulfaqar Bridge: Zulfaqar Bridge is 4.8 km to the upstream of the material mining location along Ramhormoz-Abolfares Road, connecting Jokanak and Khadijeh Villages to one another. Geographic coordinates of the bridge are: latitude: X = 378718.27 and Y = 3467955.36. Figure 7 shows a view of Zulfaqar Bridge location plan relative to the material mining site along the river.

Figure 7. Zulfaqar Bridge on A'la River in the study area

Given the importance of respecting minimum allowed distances between a material mining site and nearby hydraulic structures such as bridges and dams, Table 1 compares such distances in different standards to the distance between the mine area along A'la River and Zulfaqar Bridge. Titles of the standards used in this research are as follows:

2.4. Standards

Domestic standards:

- Standard No. 336 ≈ Iran's River Materials Extraction Guide - Ministry of Energy - Iran Water Resources Management Company
- Road Safety Law

International standards:

- GMISMQSRS ≈ Guidelines for Minimising Impacts of Sand Mining on Quality of Specific Rivers in Sabah (Malaysia) [13].
- SSMMG ≈ Sustainable Sand Mining Management Guidelines (India) [14].
- SGMFUPAG ≈ Sand and Gravel Mining Floodplain Use Permit Application Guidelines (USA) [15].
- MPRSM ≈ Management Plan for River Sand Mining (Denmark) [16].

Table 1. Comparison between safety and actual distances between a material mining site location and bridges (Zulfaqar Bridge) as per different standards

Standard Name	Permissible Distance (m)	Distance in A'la River (m)
336	150 (Important Bridge 1000)	4800
Road Safety Law	1000	4800
GMISMQSRS	150	4800
SSMMG	200 to 500	4800
SGMFUPAG	150	4800
MPRSM	1000	4800

Table 1 shows that the minimum safety distances are well respected in the case of the mining site on A’la River and Zulfaqar Bridge.

Ramhormoz Diversion Dam: Ramhormoz Diversion Dam is located 4.5 km to the downstream of the material mining site on A’la River at geographical coordinates of X = 376069.78 and Y = 3458870.21. This diversion dam is constructed at upstream of Ramhormoz City to raise water level and divert it for irrigating local agricultural lands. The presence of this dam can contribute to sedimentation in upstream of the dam. Figure 8 displays position of the dam within the study area.

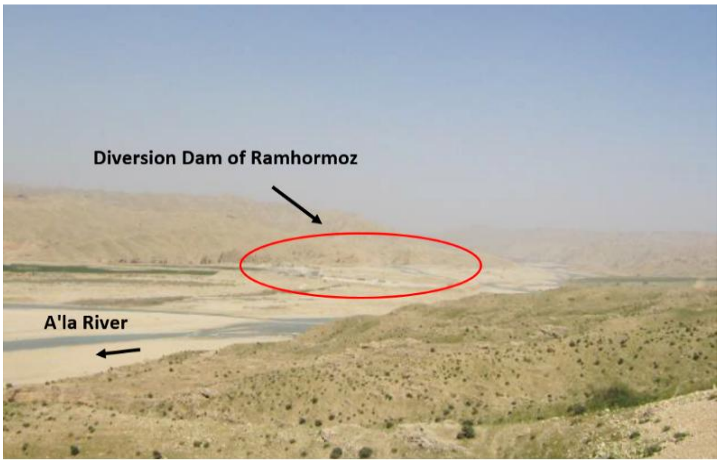

Figure 8. Position of Ramhormoz Diversion Dam

Given the importance of safety distances (as mentioned in the case of Zulfaqar Bridge) Table 2 compares actual distance between the mining site and Ramhormoz Diversion Dam to various domestic and international standards in this respect.

Table 2. Comparison of the material mining site distance from the dams in different standards and Ramhormoz dam in the A'la River

Standard Name	Permissible Distance (m)	Distance in A'la River (m)
336	150	4500
GMISMQSRS	500	4500
SSMMG	200	4500
SGMFUPAG	150	4500
MPRSM	1000	4500

Table 2 shows that the minimum safety distances are well respected in the case of the mining site on A'la River and Ramhormoz Diversion Dam.

3. Results and Discussion

Since pattern of a river is the most important factor when evaluating the river conditions via matrix method, the pattern was determined and the corresponding matrix was selected based on the obtained pattern. Required data was collected via aerial maps, site visits, reports, specialized studies, and consulting to Rivers and Coastal Engineering Office of Khouzestan Water and Power Authority (KWPA) and Ramhormoz Department of Water Affairs.

A'la River pattern was investigated in the vicinity of its intersection to Rood-Zard River and Ramhormoz Diversion Dam using satellite images taken during 2016-2017. According to the images, there are several loads and bars of sediment within the studied reach, indicating the braided pattern of the studied river (Figure 9).

Figure 9. Braided pattern of A'la River within the studied reach of the river

As can be seen from Figure 8, there are 8 points located at alignment which include the bars and sediments in stream alignment. Figures 10 and 11 show the bars and braided patterns from a closer view.

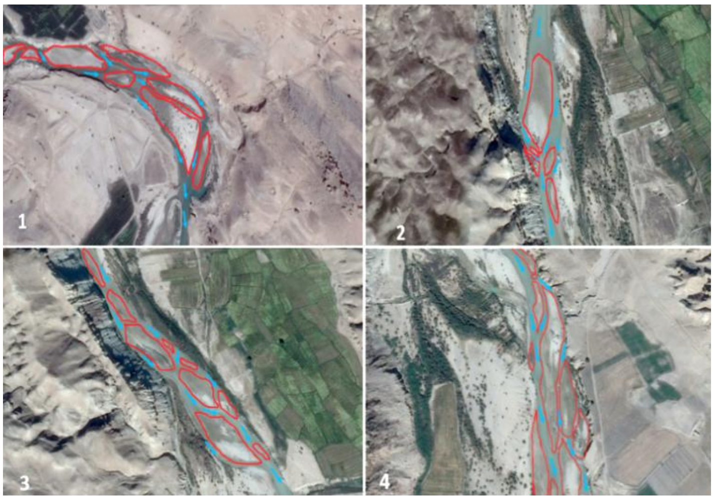

Figure 10. Points 1-4: Bars and braided pattern along A'la River

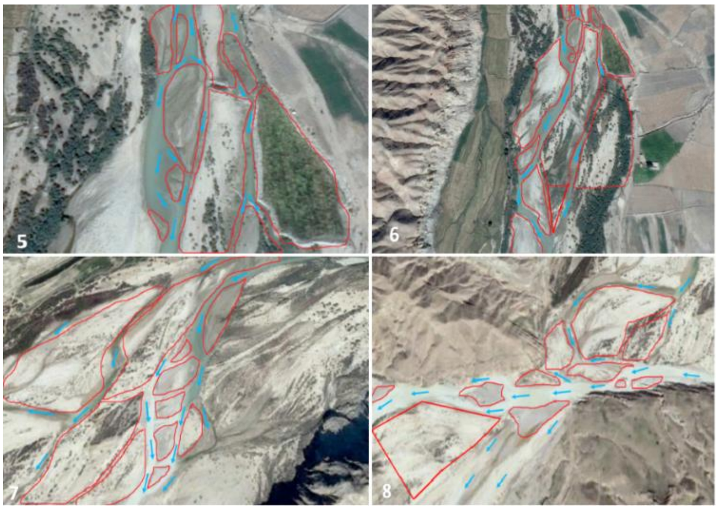

Figure 11. Points 5-8: Bars and braided pattern along A'la River

Table 3 summarizes properties of the sediments deposited along A'la River with braided pattern within the studied reach.

Table 3. Properties of the sediment bars deposited along A'la River with braided pattern within the studied reach

Point No	Geographical coordinates		Type deposition of sedimentary
1	Y=3469929	X=379697	Point Bar
2	Y=3465578.56	X=378753.22	Mid-Channel Bar
3	Y=3464846.97	X=379171.49	Mid-Channel Bar
4	Y=3463656.13	X=379839.34	Mid-Channel Bar
5	Y=3463169.38	X=379874.77	Mid-Channel Bar & Lateral Bar
6	Y=3462515.10	X=379838.64	Mid-Channel Bar & Lateral Bar
7	Y=3459806.83	X=378343.70	Mid-Channel Bar & Point Bar
8	Y=3459475.47	X=377532.67	Mid-Channel Bar

In order to be further confident about braided nature of A'la River within the study area, the criterion developed by Lane (1957) and Leopold-Wolman (1960) was used:

$$K = (SQ)^{0.25} \quad (1)$$

Where K is the criterion determining river pattern, S represents slope of the riverbed, and Q is average annual discharge of the river. According to Leopold-Wolman (1960), when computed based on values in SI system of units, a K of about 0.0125 indicates a braided river pattern. Considering the slope of A'la River within the study area (0.67%) and average annual discharge of the river (19.4 m^3/s), K value for the A'la River was calculated as 0.01406. Closeness of this value to the Leopold-Wolman’s criterion confirmed braided pattern of A'la River [17].

Based on studies, field observations and consultation with experts on the A'la River, the following brief results were obtained in the study area (intersection of Rood-Zard River and Ramhormoz Diversion Dam):

- UTM coordinates of the initial part of the reach (intersection of Rood-Zard River and A'la River) are X = 378964 m and Y = 3471253 m and those of the end of the reach (near the Ramhormoz Diversion Dam) are X=374269 Y= 3458333.
- Length of the reach is 18.5 km and slope of the riverbed is 0.67 %.
- A'la river bed is covered with coarse-grained sediments such as rubble, cobble, and coarse sand and gravel.
- A'la River is formed along a northern-southern trend with meanders developed often due to erosion. Following the meanders, the river turns southwest-ward.
- Width of A'la River in the first half of the reach (from intersection of Rood-Zard River and A'la River to the intersection of A’la River and Talkh-Rood River) varies in the range of 65-205 m, while in second half of the reach, the bed width ranges from 116 to 596 m. The variations are attributed to the entrance of the river into alluvium terrace. Average width of this river within this reach is 400 m.

- According to hydraulic studies on A'la river, the Manning coefficient at the intersection of Rood-Zard River and Talkh-Rood was $n = 0.039$, while a Manning coefficient of $n = 0.033$ was obtained at downstream of the stream.
- The river is located deep in a giant valley, so that hard rocks have limited the extension of river bed in width.
- Thalweg of the river exhibits several meanders and sediments are loaded inside them.
- A'la River receives some sedums through Rood-Zard and Talkh-Rood Rivers which affect total sediment load of the river.
- Originated from limestone and conglomerate, coarse sediments in riverbed are appropriate sources of construction materials used in local civil activities.
- Studies indicate that, the riverbed, inactive floodplain, and dry parts of river possess aggregate mining potential.
- The present research indicates that the sediment load of the river is about 250,000 m^3.
- About 70% of the sediment load of the river is loaded during December to March, a large portion of which is brought by flood events.
- The most appropriate mining method for the river was found to be deep scraping, while open-pit mining was assessed as the most inappropriate mining method.

Site inspections and consulting to experts further confirmed braided pattern of A'la River in the study area.

Figure 12 shows the mining site along A'la River together with some information on the dimensions of the mining site.

Figure 12. Geometric dimensions of the mining site within the studied reach along A'la River

Figure 13 shows a photograph of the A'la River and mining site taken during the site inspections.

Figure 13. A'la river and mining site

Table 4 provides a summary of available data on A'la River basin according to existing literature.

Table 4. Properties of A'la river basin

River Name: A'la River
Main Basin: Persian Gulf and Oman Sea Basin – Jarahi River Basin
Subsidiary Basin: A'la River Basin
Area: 2330 km^2
Perimeter: 294 km
Average Slope: 13.15%
Main Stream Length: 103 km
Average Height: 1458 m
Type of Climate and Meteorological Conditions: Semi-Arid and Hot – Semi-Humid
Type of Rainfall: Precipitation – Rain Storm
Mean Annual Rainfall: 400 mm (Meydavoud Station)
Hydrometric stations and Equipment: Jokanak Station – Stage gauge, Water Level Recorder, Cable Way
Hydraulic Structures: Ramhormoz Diversion Dam – Dam Hedge – Bridge
Dominate Vegetation: Lotus – wheat – Barley – Rice and …
Major Cities: Meydavoud – Ramhormoz
Drought and Wet Year Conditions: 36% drought years - 32% wet Year condition and Other years natural state
Basic Studies Conducted: Studies of A'la River Training Project (Sabz-Ab Arvand Co)

Table 5 gives properties of the mining site along A'la River, as determined upon the site inspections.

Table 5. Properties of mining site along A'la River

River Name: A'la River
River Reach: Rood Zard Junction to Ramhormoz Diversion Dam
Geographical Coordinates of Mining Zone: Beginning Point; X=379892 Y=3463348 – End Point; X=379813 Y=3462558
Area of Mining Zone: 50,000 m^2 (5 ha)
Size of River (Small-Average-Large): Large River
Mining Location (Active Floodplain - Inactive Floodplain- Terrace): Active Floodplain
Channel of extraction Location (Active Channel- High-Water Channel- Abandoned Channel): High-Water Channel
Type deposition of Sedimentary (Bed bar- Point Bar – Lateral Bar - Mid-Channel Bar - Inside Meander- Outside Meander- Vegetated Island- Vegetated Bank): Mid-Channel Bar
Particle Size Distribution: Coarse Size (Stone, Rubble & Gravel)
Removal Season and Time Duration: Summer - Maximum 20 Days
Type of Consumption: Construction Site
Extraction Method (Scraped- Dredging-Pit): Scraped
Extraction Length: 810 m
Extraction Width: 62 m
Extraction Depth: 1 m
Removable Volume: 50,000 m^3
Mining Machinery: Loader - Truck
Distance of Mining Zone from Hydraulic Structures: Upstream; Zolfaghar Bridge: 4.8 km – downstream; Ramhormoz Diversion Dam: 4.5 km
Nearby Cities Mine: Meydavoud - Ramhormoz
Mining Impacts: Positive Effects; River Training- Direct the Flow into the Main Channel- Increase the Capacity of the River Inflow- Negative Effects; Sudden Erosion & Instant Erosion and River Bed Achieve to the Bed Rock
Distance to the Place of Consumption: 10 km

Since the braided pattern was suggested for the A'la River at the studied reach according to the results, the specific matrix for a braided river was selected to study and evaluate aggregate mining potential of the reach, with the results reported in Table 6.

Table 6. Specific matrix for a river of braided pattern [12]

River Size			Site Location			Associated Channel			Type of Deposit								Comments
Small	**Medium**	**Large**	**Active Floodplain**	**Inactive Floodplain**	**Terrace**	**Active Channel**	**High-Water Channel**	**Abandoned Channel**	**bed**	**Point Bar**	**Lateral Bar**	**Mid-Channel Bar**	**Inside Meander**	**Outside Meander**	**Vegetated Island**	**Vegetated Bank**	
*	*	*	*			*			*								1. Gravel may be available by scraping or dredging.
*	*	*	*			*					*	*					2. Grave I available by scraping.
*	*	*	*	*			*	*			*	*					3. Gravel available by scraping.
*	*	*	*	*		*	*	*							*		4. Generally should not be mined.
*	*	*	*	*	*	*	*									*	5. Banks should not be mined.
*	*	*	*	*			*	*	*								6. Gravel available by scraping.
*	*	*			*		*		*		*	*			*		7. Gravel available by scraping.
*	*	*		*	*			*	*		*	*			*	*	8. Gravel available by scraping or pit mining.

The specific matrix for braided river has 8 rows, with the elements along each row being defined as follows:

Comment 1. Generally, bed of an active channel should not be disturbed. If deposits on the bed are the only source available, the gravel should be taken only under strict work plans end stipulations.

- It is recommended to mine side channel(s) rather than the main channel. Select side channel(s) that carry less than approximately one third of total flow during the mining period; block off upstream ends end mine by scraping operations.
- If the main channel must be mined, dredging may represent an appropriate mining method.

Comment 2. Gravel may become available by scraping gravel deposits down to near the low summer flow while maintaining appropriate buffers, or no lower than the water level during the mining operation.

Comment 3. Gravel can be extracted by scraping, such that the configuration of the channel is not changed significantly and there is not a high probability of channel diversion through the mined area.

Comment 4. Vegetated islands often serve as limited habitats in these systems and should generally be excluded from the work plan. Outcropped deposits should be mined before vegetated island deposits. In case deposits in feasible alternative locations are not sufficient and vegetated islands are abundant in the particular reach in question, up to 10-20% of this habitat may be extracted given the 5-km length of the floodplain.

Comment 5. Vegetated river banks of both active and high-water channels should not be disturbed to avoid biological and hydraulic alterations. This area should be omitted from work plans.

Comment 6. Gravel can be extracted by scraping the channel beds, but general configuration of the channels should be maintained.

Comment 7. In these systems, it is recommended to scrape exposed deposits in the active floodplain. If sufficient gravel is not available in the active floodplain, one may extract gravel by scraping these locations while maintaining general configuration of the channel.

Comment 8. In these systems it is recommended to scrape exposed deposits in the active floodplain. If sufficient gravel is not available in the active floodplain, one can extract gravel in these locations by either open-pit mining or scraping method. Generally, pits should only be considered when more than 50,000 m^3 of aggregate are required [9]. Also, a blank matrix is filled for mining site along the river (Table 7) and compared to the corresponding matrix to braided river pattern based on the data detailed in Table 6. Then, the rows with highest overlap were selected and evaluated.

Table 7. The blank matrix filled for A'la River

River Size			Site Location			Associated Channel			Type of Deposit							
Small	Medium	Large	Active Floodplain	Inactive Floodplain	Terrace	Active Channel	High-Water Channel	Abandoned Channel	bed	Point Bar	Lateral Bar	Mid-Channel Bar	Inside Meander	Outside Meander	Vegetated Island	Vegetated Bank
		√	√				√					√				

Having compared the blank (completed) and braided matrixes, mining potential of the study area was evaluated and appropriate mining method and associated necessities were determined.

The blank matrix was filled by taking the following steps:

River size: The basin area (2330 km^2) and top width (400 m) of A'la River make it classified as a large river.

Mining site: according to site inspections and aerial maps, the site with viable mining potential was located in active floodplain of the river.

Associated channel: The stream associated with the mining site of the river within the study area was high-water channel.

Type of Deposit: since the bar and deposit of mining site are located at the middle of A'la River, these bars are considered as mid-channel bar.

According to the comparison between the filled blank matrix (Table 7) and specific matrix for braided rivers (Table 6), it can be seen that a complete overlap is observed along the 3rd row of Table 6. Thus, the explanation of the 3rd row of the table is extracted. The following explanations are presented based on the 3rd row and final evaluations:

- By reviewing the maps and criteria for determining the river pattern and based on the relationship between the riverbed slope and the average annual discharge, it was realized that the A'la River is of braided pattern within the study area.
- The A'la River is classified as a large river according to the values of basin area and top width of the river.
- The considered sites for aggregate mining along A'la River is active floodplain, mid-channel bar, and high-water channel.
- The A'la River enjoys a noticeable sediment load regarding the joining of Rood-Zard and Talkh-Rood Rivers, making the river of large potentials for aggregate mining.
- Observing basic principles of material mining of rivers and taking into account environmental considerations along A'la River are of a great importance. Therefore, the river matrix method was used to verify appropriateness of the aggregate mining site.
- Scraping method is suggested as the best aggregate mining method along A'la River.
- Maximum allowed depth of aggregate mining along the river is suggested to set to 1 m.
- Minable area of the river is about 50,000 m^2.
- Minable volume of materials is estimated as 50,000 m^3.
- Aggregates should be mined in such a way not to change the stream significantly.
- The mining should be carried out without significant changes in river direction.
- Aggregate mining management along A'la River improves the river training and guides the river toward the main stream.
- Application of matrix method to assess material mining area along rivers can attenuate negative environmental impacts on the river.

All by all, the matrix method provided accurate results within the studied reach of A'la River (i.e. from Rood-Zard River intersection to Ramhormoz Diversion Dam) regarding the braided pattern of the river. Given that mining potential and mining method are the two crucial criteria for mining, the matrix method results were highly in agreement with the results of site inspections. Attenuation of negative impacts of aggregate mining out of A'la River using matrix methodology provided helpful information on mining potential of the area, appropriate mining method, etc. It is recommended to undertake similar feasibility studies using matrix method on other rivers and streams in Khouzestan Province, Iran.

4. Conclusion

Aggregate mining along riverbeds results in extensive environmental and morphological changes. Results of this research indicate that, the adoption of appropriate method for selecting material mining location can bring about positive effects and reduce negative impacts on river systems. Matrix method was used for aggregate mining location evaluation and mining method selection along A'la River, and presented acceptable results in this respect. In the present research, studying a segment of A'la River, matrix method was used to determine appropriate location for aggregate mining along the river and suitable mining method.

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